United States
Department of
Agriculture

Forest Service

Rocky Mountain
Forest and Range
Experiment Station

Fort Collins,
Colorado 80526

General Technical
Report RM-128

Silvicultural Systems and Cutting Methods for Ponderosa Pine Forests in the Front Range of the Central Rocky Mountains

Robert R. Alexander

Abstract

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed ponderosa pine forests in the Front Range into managed stands for a variety of resource needs. Guidelines consider stand conditions, and insect and disease susceptibility. Cutting practices are designed to integrate maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing, with providing wood products.

Cover Photo.—Open-grown Front Range.

USDA Forest Service
General Technical Report RM-128

May 1986

Silvicultural Systems and Cutting Methods for Ponderosa Pine Forests in the Front Range of the Central Rocky Mountains

Robert R. Alexander, Chief Silviculturist
Rocky Mountain Forest and Range Experiment Station[1]

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

	Page
NATURAL STANDS	1
AGE-CLASS DISTRIBUTION	1
REACTION TO COMPETITION	2
STAND CONDITIONS	2
DAMAGING AGENTS	2
WIND	2
INSECTS	2
Bark Beetles	2
Other Insects	3
DISEASES	3
Dwarf Mistletoe	3
Decay Fungi	4
Other Diseases	4
FIRE	4
ANIMALS	4
CUTTING HISTORY	4
REGENERATION SILVICULTURAL SYSTEMS	5
EVEN-AGED CUTTING METHODS	5
Management with Advanced Reproduction	5
Simulated Shelterwood Cutting	5
Management for Regeneration After Cutting	6
Clearcutting	6
Shelterwood Cutting	6
UNEVEN-AGED CUTTING METHODS	12
Individual-Tree Selection Cutting	13
Group Selection Cutting	13
Stand Structure Goals	13
Control of Stocking	13
Maximum Tree Size	14
Control of Diameter Distribution	14
How to Determine Residual Stand Structure	14
How to Handle Small Trees	17
Marking Trees	17
Recommendations for Selection Cutting	17
Stand Structure Goals, Cutting Treatments, and Reentry Schedules	17
Protecting the Residual Stand	18
COST OF SALE ADMINISTRATION AND LOGGING	18
MULTIPLE-USE SILVICULTURE	18
POTENTIAL TIMBER YIELDS	18
SOIL WATER RESOURCES	18
Water Yield	18
Soil Erosion	19
Nutrient Loss and Stream Water Temperature Changes	19
WILDLIFE AND RANGE RESOURCES	19
Game Habitat	19
Nongame Habitat	19
Livestock Grazing	19
RECREATION AND ESTHETICS	20
COMPARISON OF CUTTING METHODS	20
LITERATURE CITED	20

Silvicultural Systems and Cutting Methods for Ponderosa Pine Forests in the Front Range of the Central Rocky Mountains

Robert R. Alexander

Ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) (SAF Type 237), (Barrett et al. 1980) in the Front Range extends in a north-south direction along the east slope of the Rocky Mountains, from the Medicine Bow National Forest in southern Wyoming through the Arapaho-Roosevelt, Pike-San Isabel, and Rio Grande National Forests in Colorado, to the Carson National Forest in northern New Mexico (fig. 1). These timberlands occupy about 4 million acres that include grassland parks, willow fields along streams, sagebrush and oakbrush areas, and scattered cultivated fields (Gary 1985). They are continuously heavily used, because they are accessible all year for residence, recreation, and other activities (Myers 1974).

The principal values derived from these forests are the scenic beauty of the landscape and various outdoor recreation opportunities. These forests also are important habitat for a variety of wildlife, provide forage for livestock, and maintain watershed protection in an area where erosion is potentially serious following any major disturbance of the vegetative cover. Low fertility of most soils in the Front Range results in timber production potentials that vary from below average to very low. Wood products produced during treatment of forested areas for various management objectives support a small wood-products industry.

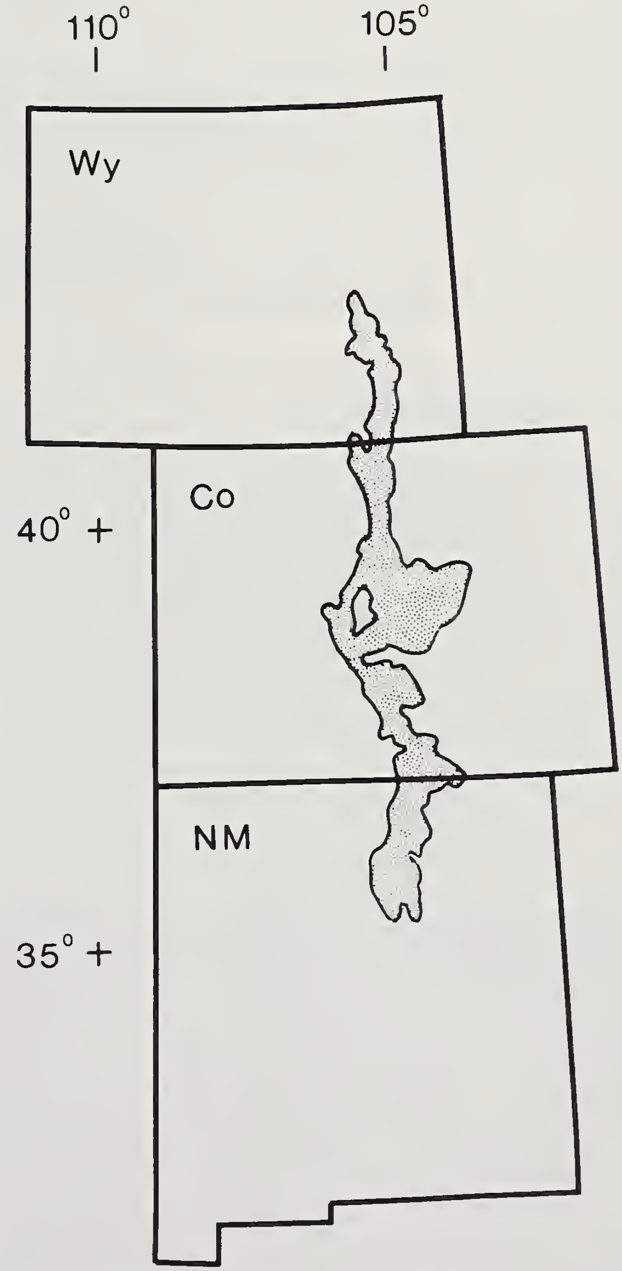

Figure 1.—Distribution of ponderosa pine in the Front Range.

NATURAL STANDS

AGE-CLASS DISTRIBUTION

There is a serious imbalance in age-class distribution in natural ponderosa pine in the Front Range. For example, in Colorado, about 60% of the stocked area is in sawtimber sized stands (Green and Van Hooser 1983). Much of these stands are overmature and declining in general vigor and soundness. If they are not replaced to create future scenic beauty and recreational areas, they will become more unattractive (Myers 1974).

Twelve percent of the ponderosa pine is in poletimber stands. Much of the poletimber is in dense patches or stands on areas of low site quality that are or will become stagnated if left untreated. Many of these stands became established after cutting or wildfires in the late 1800s. Because fires are random events, poletimber stands are abundant in some areas and rare in others. Only about 1% of the Front Range ponderosa pine is classified as seedling and sapling stands that originated after cutting or fire. About one-fourth (27%) of the ponderosa pine lands are classified as nonstocked. Failure of reproduction after cutting or fire accounts for some of the nonstocked area; but not all nonstocked lands can support ponderosa pine forests; or else they can support only open grown, low density forests (Green and Van Hooser 1983).

REACTION TO COMPETITION

Ponderosa pine is rated shade-intolerant (Baker 1949). It is comparable in shade tolerance to lodgepole pine (*Pinus contorta* Dougl. ex Loud.) but is more intolerant than associates such as Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and blue spruce (*Picea pungens* Engelm.). It is not as intolerant as aspen (*Populus tremuloides* Michx.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), and pinyon pine (*Pinus edulis* Engelm.), frequent associates in the Front Range.

Ponderosa pine in the Front Range occurs as a climax type between 6,500 and 9,000 feet elevation; but fire and/or logging has partially or completely converted many climax ponderosa pine stands to other plant communities. The kind of vegetation initially occupying the site usually determines the time it will take to return to a ponderosa pine forest. At higher and lower elevations, where ponderosa pine integrates into mixed conifer and pinyon-juniper forests, it loses its climax characteristics (Schubert 1974).

STAND CONDITIONS

Ponderosa pine forests in the Front Range form a mosaic of variations in tree size and stand density (fig. 2). They are often open-grown and poorly stocked, although many stands, patches, and groups of trees are overstocked. These forests occur mainly as irregular, multistoried stands consisting of small, even-aged groups of trees that simulate the arrangement attainable from either group selection or group shelterwood. Each even-aged group usually covers an area of 1/2 to 1 acre. Other stands are made up of patches smaller than 5 acres but larger than 1 acre. They are too large to simulate group selection or group shelterwood. Some stands appear to be single-storied and even-aged and simulate stands regenerated by clearcutting, shelterwood, or seed-tree cutting. Other stands are two-storied and resemble the seed cut of a two-cut shelterwood. These stands may appear to be highly irregular before treatment. Cutting necessary to improve the health, vigor, and appearance of such stands produces a greater uniformity in density and age structure (Myers 1974).

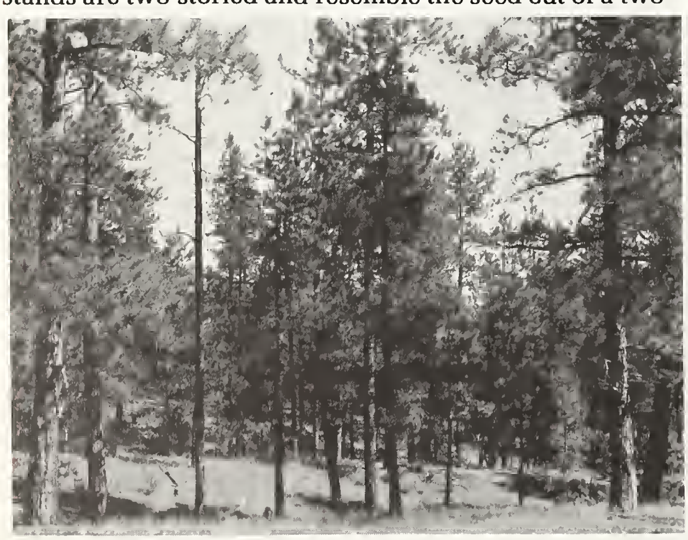

Figure 2.—Ponderosa pine in the Front Range forms a complex mosaic of different tree sizes and stand densities.

Ponderosa pine in the Front Range is frequently pure pine over much of the area it occupies; but mixed stands of pine and other species are not uncommon. In pure stands of ponderosa pine, there may or may not be an understory of reproduction, depending on the density of the overstory. If this advanced growth has not been suppressed for a long time, it will respond to release. In mixed stands, the overstory may be pure pine or pine and Douglas-fir at the middle and higher elevations on north slopes, and pine or pine and pinyon-juniper at lower elevations. Advanced growth of Douglas-fir not damaged by western spruce budworm (*Choristoneura occidentalis* Freeman) will respond to release and make good growth. In mixed ponderosa pine—pinyon-juniper stands, there is seldom any tree reproduction in the understory.

DAMAGING AGENTS

WIND

Ponderosa pine has a well-developed root system and is one of the more windfirm species in the central Rocky Mountains. Although wind is not a primary cause of damage to ponderosa pine in the Front Range, it can be damaging locally, especially in mature to overmature stands during windstorms accompanied by heavy precipitation. Generally, wind risk is not an important consideration in cutting ponderosa pine. Exceptions are those topographic situations of very high wind risk, such as ridgetops, upper windward slopes, and saddles in ridges with shallow soils; stands with many trees with defective boles and root systems; and dense stands growing on sites with a high water table.

INSECTS

Bark Beetles

Many species of insects infest ponderosa pine (Stevens et al. 1980); but the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is the most serious pest in mature to overmature ponderosa pine stands in the Front Range (Stevens et al. 1975). Epidemics have occurred throughout recorded history, and a severe outbreak in Colorado only recently subsided (fig. 3).

Adult beetles attack ponderosa pine in midsummer, usually July 15 to September 15. The beetles carry blue-stain fungi that hastens the death of the tree. Beetles create egg galleries, mate, and deposit eggs in the phloem layer. Larvae then feed on the phloem, and in conjunction with blue-stain fungi, girdle and kill the tree. The first indications of attack are pitch tubes on the trunk where the beetles have entered, and brownish dust in the bark crevices and around the base of the tree. Trees seriously attacked in the summer die almost immediately but usually do not begin to fade until the following spring. Needles change from green to yellow-green, sorrel, and finally rusty brown before dropping off years later. During outbreaks, mountain pine beetles usually kill trees in groups rather than individual trees scattered throughout the stand. These groups enlarge as subsequent generations of beetles continue the infestation, or new adjacent groups may be attacked. Groups may vary from 2 or 3 to 100 or more trees (McCambridge and Trostle 1972, Stevens et al. 1975).

All stands are not equally susceptible to attack. Epidemic outbreaks usually are associated with stands in which most of the trees are 6 inches in diameter and larger, and which are overcrowded and under stress. Infestations do not usually begin in trees smaller than 6 inches d.b.h.; but as groups of trees are killed, smaller trees, intermingled with larger trees, may be attacked and killed. Although natural factors, such as a sudden lowering of fall temperatures or prolonged subzero winter temperatures, nematodes, woodpeckers, and parasites may reduce populations, they cannot be relied upon to control outbreaks (McCambridge and Trostle 1972). Direct control of outbreaks with chemicals is expensive and often only a holding action until potentially susceptible trees can be cut. High value trees in campgrounds and recreation areas may be protected by preventative sprays.

The red turpentine beetle (*Dendroctonus valens* LeConte) attacks the base of trees and freshly cut logs and stumps of ponderosa pine (Furniss and Carolin 1977). It is not an aggressive tree killer but frequently weakens trees, making them susceptible to other bark beetles. Populations may increase in areas where logging has occurred for several consecutive years and then may move to adjacent stands. Attacks are characterized by reddish pitch tubes on the lower portion of the stem and heavy frass around the base of the tree. Damage is seldom serious enough to warrant treatment except in high-value areas. Chemical control is the most effective way to control these beetles.

The pine engraver beetles (*Ips* spp.) are also potentially destructive bark beetles although they are normally

Figure 3.—Mountain pine beetle infestations kill trees and reduce the attractiveness of ponderosa pine.

secondary insects in the Front Range (Stevens et al. 1980). Pine engraver populations commonly develop in logging slash, especially if it is shaded or does not dry out quickly for other reasons. The most effective control is removing or burning large slash and exposing small slash to direct sunlight and wind so it dries rapidly (Sartwell et al. 1971).

Other Insects

Other insect pests generally do not cause widespread losses but can be locally serious. Tip and shoot moth larvae may cause distorted or forked crowns and dead terminals and lateral shoots; sawflies, pine butterflies, and pandora moths can defoliate trees. Control of these insects is usually expensive and difficult.

DISEASES

Dwarf Mistletoe

Dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodium* (Engelm.) Hawksworth and Wiens) is one of the most serious diseases affecting ponderosa pine in the Front Range of Colorado and New Mexico (fig. 4). It is present on about 20% of the ponderosa pine acreage in the Front Range National Forests (Johnson et al. 1984). Dwarf mistletoe reduces growth and seed production and increases mortality. The rate of mortality depends largely on the age of the host tree when attacked. Young trees die quickly, while older trees with well-developed and vigorous crowns may not show appreciable effects for years. Dwarf mistletoe is most damaging in stands that have been partially opened up by cutting, mountain pine beetles, or windfall and of least consequence on regenerated burns following catastrophic fires. Heavily infected old-growth stands frequently have less than 50% of the volume of comparable uninfected stands.

Dwarf mistletoe is a parasitic plant that flowers in April and May. At maturity (July and August), fruits are forcibly ejected for distances up to 30 feet. Seeds are covered with a gelatinous material, which acts as a lubricant when wet from rain, and facilitates movement from pine needles onto branches where infection takes place. Rate of spread of dwarf mistletoe is slow—about 1.7 feet per year in open and 1.2 feet per year in dense, immature stands (Lightle and Weiss 1974).

The disease is difficult to detect in recently infected stands, because trees show no abnormalities except for the inconspicuous shoots on branches and main stems. Where the parasite has been present for a long time, stands will have one or more heavily damaged centers characterized by many trees with witches' brooms, spiketops, and an above-average number of snags with remnants of brooms (Lightle and Weiss 1974). Although optimum development is favored by a vigorous host, and the most vigorous trees are most heavily infected, frequency of infection is usually higher on poor sites.

To quantify the severity of infection, Hawksworth (1961, 1977) developed the 6-class mistletoe rating system (fig. 5). Average stand rating is computed by averaging the dwarf mistletoe ratings (DMR) for all trees in the stand, including noninfected trees. Average stand DMRs in untreated stands can be estimated from the percentage of tree infection in the stand. The relationship of average stand DMR to proportion of trees is as follows:

Percent of trees infected	DMR
10	0.17
20	0.24
30	0.35
40	0.52
50	0.76
60	1.11
70	1.62
80	2.37
90	3.46
100	5.06

Decay Fungi

The major root and stem fungi attacking ponderosa pine in the Front Range are red rot (*Dichomitus squalens* (Karst.) Reid) and Armillaria root disease (*Armillaria mellea* (Vahl:Fr.) Quel.) (Hepting 1971).

As old-growth is converted to managed stands, decay fungi can be expected to decrease. Early removal of ponderosa pine with known indicators of defect will help to establish healthy, vigorous forests with greater growth potential. Rot losses in future stands can be minimized by shorter cutting rotations—120 years. Close supervision of logging operations to reduce mechanical injuries will minimize points of entry for decay fungi. Proper slash disposal will lower inoculum potential of rot fungi in residual stands. These sanitation measures are important, because direct control of rots are not possible.

Other Diseases

Limb rust (*Peridermium filamentosum* Pk.) kills ponderosa pine throughout its range. It is a systemic disease which spreads throughout the tree. The rust normally occurs in older trees and is always fatal (Peterson and Shurtleff 1965). Other diseases that attack ponderosa pine are of minor significance.

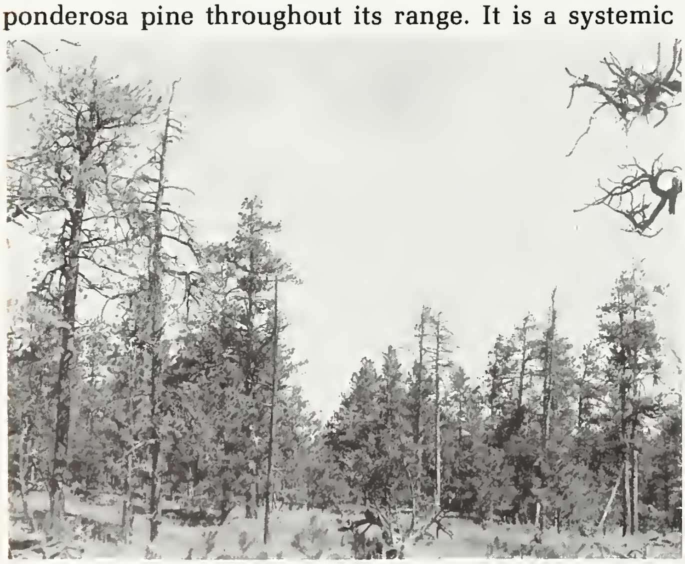

Figure 4.—Heavy dwarf mistletoe infestions reduce growth and scenic beauty.

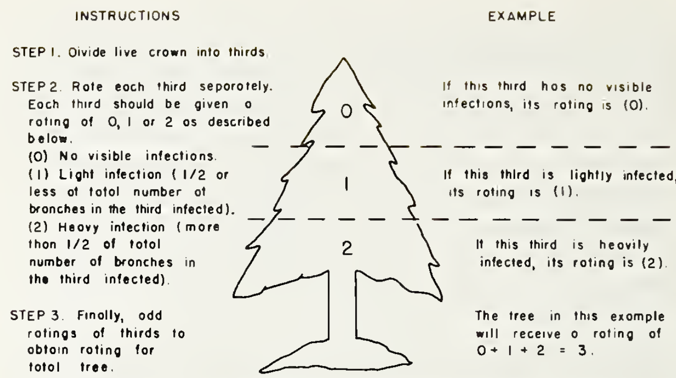

Figure 5.—The 6-class dwarf mistletoe rating system.

FIRE

The effect of fire on the character of ponderosa pine stands depends upon the age and density of the stand and the intensity of the fire. Low intensity ground fires damage dense seedling, sapling, and pole stands; but older trees are quite resistant. High intensity crown fires destroy all trees in the burned area. Many large trees have fire scars which reduce the value of the butt log. Dense young stands should be thinned to reduce the probability of crown fires. Fuel breaks should be placed along heavily traveled roads and around high value sites.

Controlled or prescribed burning has not been used much in ponderosa pine forests in the Front Range but offers a management opportunity in mature stands without a stand of advanced reproduction. Low intensity surface fires can be used to prepare seedbeds, reduce competing vegetation, and eliminate fire hazards without damage to the residual stand.

ANIMALS

Animal damage to established ponderosa pine forests is usually more severe in young trees; but damage to older trees can be serious. Mule deer (*Odocoileus hemionus* Rafinesque) and elk (*Cervus elaphus* L.) may browse ponderosa pine. Porcupines (*Erethizon dorsatum* Brandt) may cause serious damage by girdling trees; but losses are usually localized. At times, twig cutting by abert squirrels (*Sciurus aberti* Woodhouse) can be severe enough to kill trees or weaken them to the point that insects and diseases cause death.

CUTTING HISTORY

Cuttings of ponderosa pine in the Front Range first occurred about 1860 (Clapp 1910, Pearson 1912). During the Gold Rush, many thousands of acres were virtually clearcut for fuel, mine timbers, and lumber. Pioneer ranchers also used ponderosa pine for fuel, fence posts, and lumber. Areas not clearcut were high graded on a selective basis. Many of the clearcut areas were subsequently burned and are now poorly stocked with second-growth or are nonstocked. Following World War I, some form of partial cutting became standard practice on national forests. However, some diameter limit (10- to 12-inch minimum) cuttings were still made on private lands. Cuts on national forest lands averaged about 50% of the volume, primarily removing mature and decadent trees (Schubert 1954).

On many national forests, "selective cuttings" were made in a series of light cuts which generally amount to a shelterwood (Clapp 1910, Pearson 1912). These light cuts eventually removed 60% to 70% of the volume. A removal cut was made 10 to 20 years later, after reproduction became established.

Foresters recognized early the importance of the group and/or irregular stand structure common to ponderosa pine in the Front Range, and the need to modify cutting practices to take advantage of "natural" stand structure and constrain cutting in areas where reproduction was not already established. Another need was for sanitation salvage cutting to reduce heavy natural mortality of the larger and older trees caused by lightning, dwarf mistletoe, and bark beetles (Schubert 1974).

In the early 1940s, sanitation salvage cutting was generally replaced by individual-tree selection (improvement selection) aimed at improving the quality, reducing the density of growing stock, and salvaging mortality. In the early 1960s, cutting shifted to (1) a modified shelterwood with the first cut either a seed cut or a final removal, depending upon the amount of reproduction in the stand, with the objective of maintaining the present irregular stand structure and diversity between and within vegetative types; (2) thinning dense even-aged groups and/or stands; and (3) removal of badly diseased or dying trees that overtopped future growing stock.

Past logging, insect and disease problems, fires, and irregularities of reproduction resulting from the variability of weather generally have left ponderosa pine forests in the Front Range with little resemblance of managed, regulated forests (Myers 1964). However, in recent years, some progress has been made with sanitation and improvement cuts. While forests still are not regulated, significant progress toward managed stand conditions has been made in more accessible areas.

REGENERATION SILVICULTURAL SYSTEMS

Ponderosa pine forests in the Front Range can be harvested by both even- and uneven-aged silvicultural systems. They can be harvested by all even- and uneven-aged cutting methods and their modifications. However, not all cutting methods are recommended. Clearcutting in patches is an effective method of controlling dwarf mistletoe and mountain pine beetles; but regeneration success has been varied. Similarly, the seed-tree method has not been successful in regenerating ponderosa pine. Individual-tree selection can be applied to some stands; but the silvical characteristics and the stand conditions of ponderosa pine in the Front Range are not generally suited to individual-tree selection cutting (Ronco and Ready 1983). The objective of each regeneration system is to harvest the timber crop and obtain adequate reproduction. The choice of cutting method in ponderosa pine stands depends upon management goals; but stand conditions, disease and insect susceptibility, and the risk of potential fire damage that vary from place to place on any area limit the options available for handling individual stands. Furthermore, the economics of harvesting, manufacturing, and marketing wood products from many small diameter trees in the central Rocky Mountains further limits cutting practices. Cutting to bring ponderosa pine in the Front Range under management is likely to be a compromise between what is desirable and what is possible. Management on many areas may involve a combination of several cutting treatments (Myers 1974).

EVEN-AGED CUTTING METHODS

Shelterwood is the preferred even-aged method for ponderosa pine in the Front Range, in stands where disease and insect problems do not require clearcutting.

Management with Advanced Reproduction

Simulated Shelterwood Cutting

This cutting method, generally applicable to two-storied stands, removes the overstory from a manageable stand of advanced reproduction. It simulates the final harvest of a standard shelterwood.

Stands may be pure ponderosa or mixed with a ponderosa pine overstory and a pine/Douglas-fir understory. Understory trees respond to release after cutting; but wide variations in age, composition, quality, and quantity of advanced reproduction require careful evaluation of the potential for future management. One course of action is followed if the advanced reproduction is to be managed, another if a manageable stand is not present, cannot be saved, or the manager chooses to destroy it and start over.

Prelogging evaluation.—The initial examination must answer the following questions: (1) How much of the area is stocked with acceptable seedlings and saplings, and will that stocking insure a satisfactory replacement stand? (2) Can it be logged economically by methods that will save advanced reproduction? Is the timber volume too heavy to save advanced reproduction if it is removed in one cut? (3) How much of the area will require subsequent natural or artificial regeneration, either because advanced reproduction is not present or will be damaged or destroyed in logging?

Because any kind of cutting is likely to destroy at least 50% of the advanced growth, a manageable stand of advanced reproduction before cutting should contain at least 600 acceptable seedlings and saplings per acre. Stands or portions of stands not meeting these criteria have to be restocked with subsequent natural or artificial regeneration.

Cutting and slash disposal treatment.—Mature and overmature trees should be cut to release advanced reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in stocking. The size, shape, and arrangement of units cut is not critical for regeneration; but to be compatible with other key uses, they should be irregular in shape.

Protection of advanced reproduction begins with a well-designed logging plan. Logging equipment and activity must be rigidly controlled to minimize damage to advanced reproduction and disturbance to soil. Skidroads should be located at least 200 feet apart and marked on the ground before cutting. Skidding equipment should be moved only on skidroads. Where possible, trees should be felled into openings at a herringbone angle to the skidroad to reduce disturbance when logs are moved onto the skidroad. It may be necessary to deviate from a herringbone felling angle in order to drop the trees into openings. In this case, the logs will have to be bucked into short lengths to reduce skidding damage. Furthermore, the felling and skidding operations must be closely coordinated, because it may be necessary to fell and skid one tree before another is felled. Dead sound material and snags that are felled should be skidded out of the area to minimize the amount of slash and unmerchantable material. In stands with heavy volumes per acre, it may be necessary to remove the overstory in more than one cut.

Slash treatment then should be confined to areas of heavy concentrations as required for protection from fire and insects or preservation of esthetic values. Slash also must be treated carefully to avoid damage to advanced reproduction. If trees are felled into openings as much as possible, a minimum of turning and travel with brush dozers will be needed to concentrate the slash for burning. Slash piles should be large enough to confine burning to the smallest total area possible.

Postlogging reevaluation.—Even with careful logging and slash treatment, some advanced reproduction will be damaged or destroyed. The area must be surveyed to: (1) Determine the extent of damage to the reproduction. At least 300 acceptable seedlings and saplings per acre must have survived to consider the area adequately stocked. This is in addition to any trees larger than 4 inches d.b.h. that survived. Areas that do not meet these standards need fill-in or supplemental stocking. (2) Plan stand improvement—cleaning, weeding, and thinning—to release crop trees. Cutover areas should not be considered in an adequate growing condition until the crop trees are free to grow and the necessary fill-in planting or natural regeneration is complete.

Management for Regeneration After Cutting

Clearcutting

This method harvests the timber crop in one step to establish a new stand. Clearcutting ponderosa pine in the Front Range is not recommended, except where there is no alternative for solving severe insect and disease problems, discussed later.

Shelterwood Cutting

This method harvests a timber stand in a series of cuts. It is applicable to single-storied ponderosa pine or two-storied stands without a manageable stand of advanced reproduction. In a standard shelterwood, the new stand regenerates under the shade of a partial overstory canopy. The final harvest removes the shelterwood and permits a new stand to develop in the opening. Group shelterwood (a modification of the shelterwood method) is applicable in stands composed of irregular mosaics of small even-aged groups or poles of trees. The new stand regenerates in small openings that leave standing trees around the margins as a seed source. Openings are too small (2 acres or less) to be classified as a clearcut. This kind of cutting has been incorrectly called a modified group selection but differs from a selection cut in the way the growing stock is regulated.

These cutting methods are usually the only even-aged options available for ponderosa pine in the Front Range. However, shelterwood cutting requires careful marking of individual trees or groups of trees to be removed and close supervision of logging. The following recommendations for shelterwood cutting practices are keyed to broad stand descriptions based largely on experience, and disease and insect problems (Myers 1974, Ronco and Ready 1983, Schubert 1974). Practices needed to obtain natural reproduction are also discussed. Stands are pure pine unless otherwise indicated.

Single- and two-storied stands.—Single-storied stands may appear to be even-aged and two-storied stands two-aged (fig. 6), but often contain more than one or two age classes; occasionally they may even be broad-aged. If even-aged in appearance, there is a small range in diameter and crown classes. In single-storied stands, codominants form the general level of the canopy; but the difference in height between dominants, codominants, and intermediates is not great. In two-storied stands, top story resembles a single-storied stand. The second story is composed of younger trees of smaller

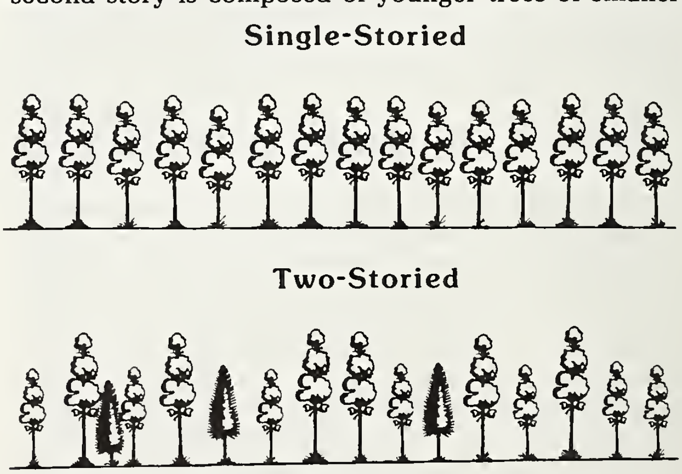

Figure 6.—Single- and two-storied ponderosa pine stands.

diameter. If the stand is two-storied and more than two-aged, the overstory usually contains at least two ages classes. The younger trees are finer limbed and are smaller in diameter. Stocking of single-storied stands may be uniform. Stocking of the overstory in two-storied stands may be irregular; but overall stocking may appear to be uniform. A manageable stand of advanced reproduction usually is absent.

In mixed single-storied stands, the overstory is either (1) pure pine or (2) pine and Douglas-fir, with advanced reproduction largely Douglas-fir that may or may not be a manageable stand. In mixed two-storied stands, the overstory usually is pure pine but may be pine and Douglas-fir. The second story usually is mixed pine and Douglas-fir but may be largely Douglas-fir. Stocking in mixed stands varies from uniform to irregular.

A two-cut shelterwood usually is appropriate in stands that have been previously entered. A three-cut shelterwood often is more desirable in stands not previously entered, especially those susceptible to windthrow.

Using a three-cut shelterwood in stands that are uniformly spaced, the first entry should remove 30% to 40% of the basal area on an individual-tree basis (fig. 7). This initial entry is a preparatory cut, because it probably does not open up the stand enough for pine reproduction to become established significantly. The general level of the canopy should be maintained by removing some trees in each overstory crown class. The cut should come from the poorest vigor class trees; but openings larger than one tree height in diameter should be avoided by distributing the cut over the entire area. In mixed stands, if the overstory is mostly pine, handle it as a pure stand; if the overstory is of mixed composition, cut as much of the basal area recommended in pine as is possible to release the Douglas-fir, provided there are no serious budworm problems.

The second entry into the stand can be made in 5 to 10 years after the first cut. The second cut should remove 30% to 40% of the original basal area on an individual-tree basis. This seed cut opens up the stand so that pine

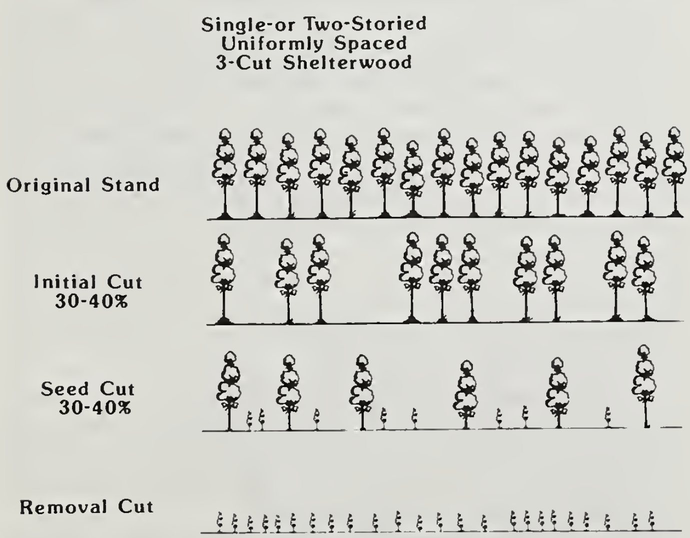

Figure 7.—Sequence of entries with a 3-cut shelterwood in a uniformly spaced, single- or two-storied ponderosa pine stand.

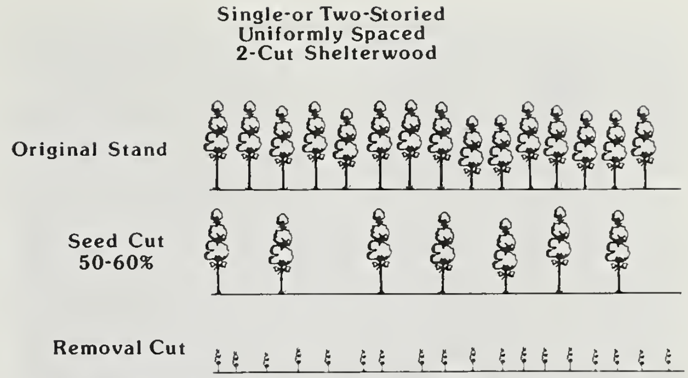

Figure 8.—Sequence of entries with a 2-cut shelterwood in a uniformly spaced, single- or two-storied ponderosa pine stand.

regeneration can become established. The largest and most vigorous dominants and codominants should be reserved as a seed source; but avoid cutting openings in the canopy larger than one tree height in diameter by distributing the cut over the entire area, even if it means leaving trees in the C and D vigor classes with poor seed production potential. In mixed stands, cut as much of the recommended basal area in pine as is possible without creating openings larger than one tree height.

The last entry into these uniformly spaced stands is the final harvest which should remove all of the remaining original overstory. It should not be made until a manageable stand of reproduction has become established; but the cut should not be delayed beyond this point because the overwood (1) hampers the later growth of seedlings, and (2) if infected with dwarf mistletoe, it will reinfect the new stand.

The manager also has the option of removing less than 30% of the basal area at any entry and making more entries; but they should be made at more frequent intervals. The cut will be spread out, and continuous high forest cover will be maintained for a longer time. This option is not recommended where mountain pine beetles and dwarf mistletoe limit how stands can be handled.

Using a two-cut shelterwood in stands that are uniformly spaced, the first cut can remove up to 50% to 60% of the basal area (fig. 8). About 50% of this cut should come from the second story of a two-storied stand, because it is necessary to reserve some of the better dominants as a seed source. This cutting is the seed cut; but trees are marked on an individual-tree basis. Trees removed should be in vigor classes C and D insofar as possible; but selected dominants and codominants should be left even when they are in vigor classes C and D if they do not have dead or dying tops. Avoid cutting holes in the canopy by distributing the cut over the entire area. In mixed stands, if the top story or the first and second stories are pure pine, handle them as pure stands. If the top story is of mixed composition, cut as much of the basal area to be removed in pine as is possible to release the Douglas-fir; but do not cut all of the pine if it is needed to maintain the overstory.

The second entry should be the final harvest to remove the remaining original stand and release the reproduction. It cannot be made until the new stand of reproduction is established.

The manager has other options, including cutting less than the recommended basal area, making more entries, and spreading the cut out over a longer time by delaying the final harvest until the new stand is tall enough to create the appearance of a high forest. This is not recommended where mountain pine beetles and dwarf mistletoe limit how stands can be handled.

For stands with clumpy or irregular spacing, using either a two- or three-cut group shelterwood, the usual uniform arrangement of individual trees in single-storied stands is less likely to occur in ponderosa pine in the Front Range than in other Rocky Mountain timber types. Natural openings occur in many single-storied and two-storied stands. In other clumpy or irregularly-spaced stands, openings may have resulted from the break-up of single-storied stands, beetle attacks, or fires.

With a three-cut alternative, the first entry should remove about 30% of the basal area using a group shelterwood (fig. 9). Openings should be kept small and should conform to the natural arrangement of the stands; but not more than one-third of the area should be cut over at any one time. The second entry into the stand should not be made until the first openings have been regenerated. This cut should remove about 30% to 40% of the original basal area without cutting over more than an additional one-third of the area. The final entry should remove the remaining groups of merchantable trees.

With a two-cut alternative, the first cut can remove about 40% to 50% of the basal area in a group shelterwood (fig. 10). The group openings can be two or three times tree height; but the area cut over should not exceed about one-half of the total. Openings should be irregular in shape to simulate natural openings. One additional entry can be made in the stand to remove the remaining original basal area in group openings up to two to three times tree height.

With both alternatives, the timing of the final entry depends on how the manager decides to regenerate the openings. Using natural regeneration, the final harvest either must be delayed until the trees in the original openings are large enough to provide a seed source, or these openings are planted, or a standard shelterwood is applied to the last groups. In the last case, it will require at least one additional entry to remove the overstory after reproduction has established.

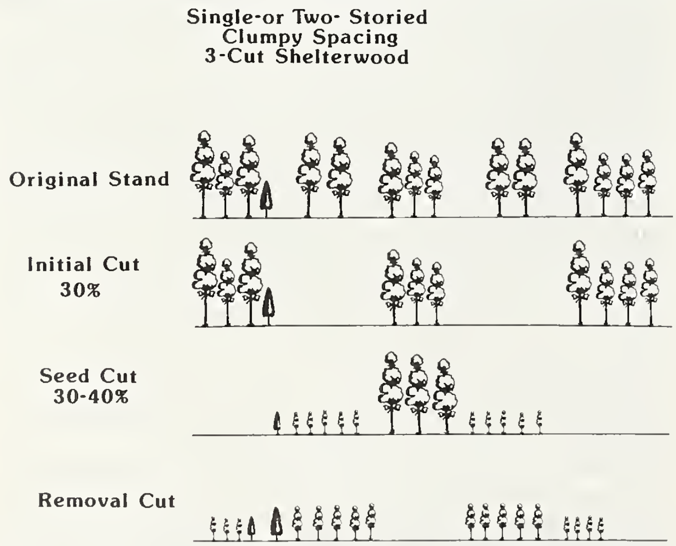

Figure 9.—Sequence of entries with a 3-cut group shelterwood in an irregularly spaced, single- or two-storied ponderosa pine stand.

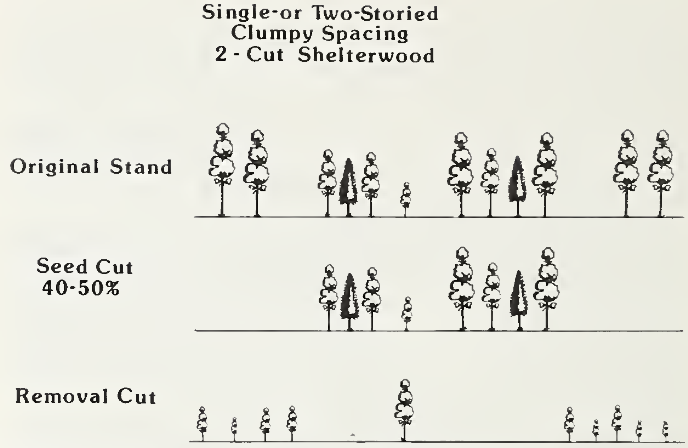

Figure 10.—Sequence of entries with a 2-cut group shelterwood in an irregularly spaced, single- or two-storied ponderosa pine stand.

With either alternative, the manager may choose to remove less than the recommended basal area and cut over less than the recommended area at any time. This will require more entries and spread the cut over a longer time; but each new cut should not be made until the openings cut the previous entry have regenerated. Furthermore, the last groups cannot be cut until there is either an outside seed source, the openings are planted, or a standard shelterwood is applied to the last groups.

Group shelterwood cutting is not applicable in pure stands where mountain pine beetle or dwarf mistletoe impose limitations, because the interval between initial cutting and final harvest is likely to be too long to prevent serious mistletoe infection of new reproductive and/or loss of beetle-susceptible trees.

Multistoried stands.—These stands usually are uneven- to broad-aged (fig. 11), with an irregular mosaic of small even-aged patches of trees of less than 5 acres or small even-aged groups of trees each less than 1 acre. If stands developed from relatively few individuals after disturbance, the overstory trees are coarse limbed. Fill-in trees are better formed and finer limbed. Vigor of the overstory trees varies from poor to good. In stands that developed from deterioration of single- or two-storied stands, the overstory trees may be no limbier than the fill-in trees. Nearly all of the healthy, faster growing trees are below saw-log size. Stocking may be irregular within patches or groups. A manageable stand of advanced reproduction may be present.

In mixed stands, the overstory may be either (1) pure pine, or (2) a mixture of pine and Douglas-fir. Stocking in mixed stands is likely to be irregular. Mixed stands frequently have a manageable stand of advanced reproduction of species other than pine.

There is considerable flexibility in harvesting these multistoried stands. They can be managed as either even- or uneven-aged.

To convert irregular multistoried stands composed of a mosaic of even-aged groups and/or patches to even-aged stands, groups and patches that differ only moderately in diameter classes are combined into stands and then cut to create a greater uniformity in diameter classes (fig. 12). Dense groups or patches of immature trees should be thinned to reduce stand density (fig. 13). Emphasis should be on thinning from below with the removal of enough dominants and codominants to stimulate growth. Immature groups and/or patches not dense enough to require thinning should receive an improvement cut to remove diseased and dying trees and any scattered remnant overstory trees left from past cutting or fires.

Some irregular multistoried stands have a light overstory over groups and/or patches of immature trees ranging from reproduction to small poles that cover large areas that can be treated as stands. These are converted by removing the scattered overstory and thinning and improvement cutting in the understory to create a more uniform diameter distribution (fig. 12).

Irregular multistoried stands should be converted to even-aged structure with a minimum impact on growing stock. The time needed for conversion depends upon stand conditions; but in most stands it is likely to require the rest of the rotation. Shelterwood or other even-aged cutting methods would be used to maintain the stand structure.

To convert irregular multistoried stands composed of a mosaic of even-aged groups and/or patches with trees in the smaller and intermediate size classes to uneven-aged stands, maintain the integrity of the groups and subdivide the patches to create groups of about 2 acres or less in area (fig. 14). These groups may contain trees of different size classes. Groups containing trees of about the same size are treated to create a range of size classes. Some groups are heavily thinned, others lightly thinned, and in still others thinning is deferred. Trees in the heavily thinned groups grow faster and reach larger size earlier, whereas trees in the lightly thinned and unthinned groups grow more slowly and remain in the smaller size classes. Thinning to intermediate densities could create other size class groups. Improvement cutting usually is needed with thinning to remove diseased and dying trees.

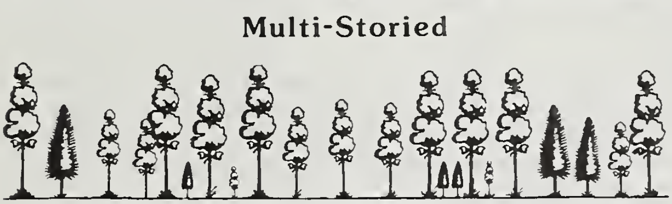

Figure 11.—Multistoried ponderosa pine stand.

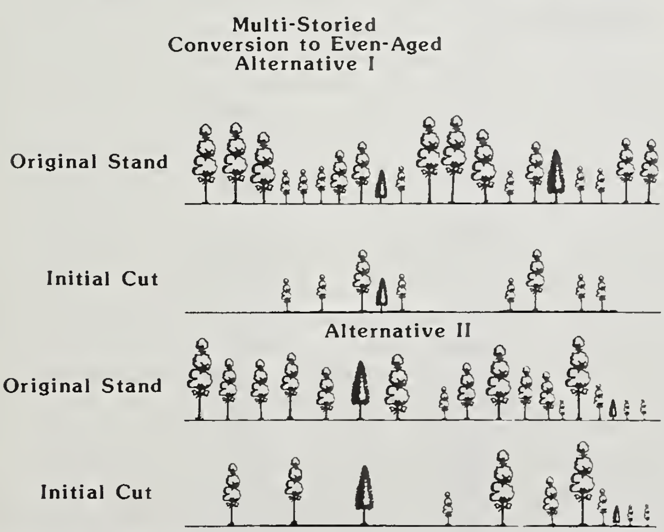

Figure 12.—Sequence of entries to convert multistoried ponderosa pine to even-aged stands.

Figure 13.—Dense patches of ponderosa pine in the Front Range should be thinned to improve productivity and appearance.

Irregular stands with larger trees also can be treated to create a range of size classes (fig. 14). Those groups composed of the largest and most defective trees are cut first to create a new small size class when regeneration becomes established in the openings. Other groups receive an intermediate cut, while other groups are left uncut to create different size classes. Variations of existing stand conditions are the basis for cutting treatments.

Once stands have been created that are composed of groups of trees of different sizes, they can be further differentiated and maintained by individual-tree and/or group selection, as discussed in the section on Uneven-Aged Cutting Methods. Time required for conversion depends upon the original stand conditions.

Reserve stands.—The number of trees left standing after partial cutting is a major factor in attaining the objectives of intermediate and regeneration cuts. A numerical system for designating this stocking is needed. The site quality of most ponderosa pine lands in the Front Range is relatively poor (site index 40 to 60). Site index is measured in feet at base age 100 years. This means that stocking levels must be lower than other ponderosa pine forests. For even-aged stands and even-aged groups created by standard and group shelterwood in single- and two-storied stands, and the mosaic of groups, patches, and stands created in multistoried stands being converted to even-aged management, the recommended stocking level should range from GSLs 40 to 80.

Stand density after treatment, expressed as GSL, is the relationship between basal area and average stand diameter after cutting. A GSL is named by the basal area desired when average stand diameter is 10 inches. Basal areas increase with diameter until 10 inches is reached, and remain constant thereafter. The designation "growing stock level 40" indicates that basal area is to be 40 square feet when average stand diameter after cutting is ≥10 inches. How basal areas vary with GSL in stands of equal average diameter is shown in table 1. Marking crews may prefer to use average distance between trees rather than basal area as a guide to reserve stocking. Equivalent distance for the GSL and diameter combinations in table 1 and for larger diameters are given in table 2.

Stand density specifications described previously create an estimation problem when average diameter after cutting will be less than 10 inches. The basal area to be left is based on the unknown posttreatment average

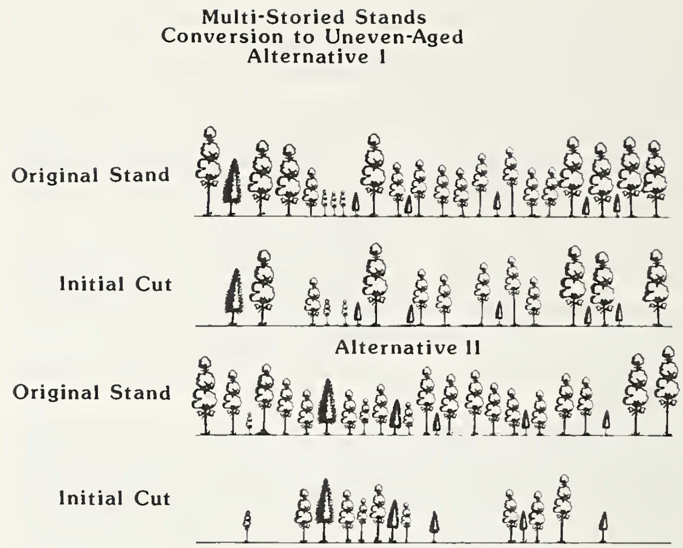

Figure 14.—Sequence of entries to convert multistoried ponderosa pine to uneven-aged stands.

Table 1.—Basal areas (in square feet) after partial cutting in relation to average stand diameter (in inches), growing stock levels 40 to 100.

Average d.b.h. after cutting	Growing stock level 40	60	80	100
1.0	3.0	4.5	6.0	7.5
2.0	6.0	9.1	12.1	15.1
3.0	11.8	17.7	23.7	29.6
4.0	17.6	26.4	35.2	44.1
5.0	23.4	35.1	46.8	58.5
6.0	28.3	42.5	56.6	70.8
7.0	32.7	49.0	65.4	81.7
8.0	36.3	54.4	72.5	90.6
9.0	38.8	58.1	77.5	96.9
10.0+	40.0	60.0	80.0	100.0

Table 2.—Average distance (in feet) between residual trees for different growing stock levels for ponderosa pine.

Average d.b.h. after cutting (inches	Growing stock level 40	60	80	100
1.0	8.9	7.3	6.3	5.6
2.0	12.5	10.2	8.9	7.9
3.0	13.4	11.0	9.5	8.5
4.0	14.7	12.0	10.4	9.3
5.0	15.9	13.0	11.3	10.1
6.0	17.4	14.2	12.3	11.0
7.0	18.9	15.4	13.3	11.9
8.0	20.5	16.7	14.5	13.0
9.0	22.3	18.2	15.8	14.1
10.0	24.4	19.9	17.2	15.4
11.0	26.8	21.9	19.0	17.0
12.0	29.2	23.9	20.7	18.5
13.0	31.7	25.9	22.4	20.0
14.0	34.1	27.9	24.1	21.6
15.0	36.6	29.8	25.8	23.1
16.0	39.0	31.8	27.6	24.7
17.0	41.4	33.8	29.3	26.2
18.0	43.9	35.8	31.0	27.7
19.0	46.3	37.8	32.7	29.3
20.0	48.7	39.8	34.5	30.8

diameter. Therefore, it is necessary to estimate diameter after cutting and to determine the basal area goal. Experience on treatment areas has shown that crews adapt readily to this procedure.

Markers must remember that level 40 does not mean a reserve basal area of 40 square feet per acre unless average diameter after cutting is 10 inches d.b.h. or larger. For smaller average diameters, level 40 means that less, sometimes much less, than 40 square feet is to be left. Also, reserve basal area is determined for each individual group or stand treated, not as an average for widely dissimilar conditions.

Marking crews first should walk through each part of the treatment area to determine the type of cutting required and to obtain a mental picture of the group or stand that should be left. Many patches are so small that a marker in the middle of the area can see the patch boundaries. Minor adjustments in the estimate of average diameter after cutting can be made, if necessary, as marking continues. Basal areas of leave trees should be checked periodically with a prism or other angle gage.

Most thinnings can be controlled by marking either the trees to be taken or those to be left. If cutting removes only trees too small for posts or small poles, it may be more efficient to use demonstration marking. In the latter case, several patches of trees, each of different average tree diameter, should be marked to the residual basal areas desired. This can be done by flagging the reserve trees. Members of the thinning crews visit these sample areas as often as necessary for them to become familiar with the spacings and densities desired for various average diameters. Flagged patches remain unthinned until they are no longer needed as demonstrations (Myers 1974).

Modifications for disease and insect problems.—In general, partial cutting should be limited to stands where the average dwarf mistletoe rating is 3 or less. Remove only the percentage of basal area recommended for the stand description, except that cutting of infected trees is emphasized. In single-storied stands, trees in the intermediate and lower crown classes should be removed before dominants and codominants. In two-storied stands, as much of the first cut as possible should come from the second story, because those trees are likely to be more heavily infected than the top story. In single- and two-storied stands, the final overstory removal can be delayed until the new reproduction is tall enough to provide a forest aspect. To minimize infection of new reproduction, however, the time interval should not exceed 30 years after the regeneration cut when the average mistletoe rating is 1, or 20 years when the rating is 2. The young stand should be sanitized at the final harvest (Beatty 1982). In multistoried stands, the safest procedure is an overwood removal coupled with improvement cutting and thinning to remove infected trees.

In old-growth stands with an average dwarf mistletoe rating greater than 3, any partial cutting or thinning is likely to intensify the infection. The safest procedure, therefore, is to either clearcut all of the trees and start a new stand, or leave the stand uncut. Clearcut areas should not be more than 150 feet from the seed source if regeneration is to be obtained from natural seeding, otherwise plan on planting the cleared area (Heidmann 1983). If the manager chooses to make a partial cut in a single- or two-storied stand for any reason, the initial harvest should be heavy enough to be a regeneration cut where there is no understory stand. Seed trees may be hard to find in heavily infected stands. All residual trees must be removed within 10 years after regeneration is established, and the young stand should be sanitized at that time (Beatty 1982). In two-storied stands with an acceptable stand of reproduction, the cut should be a simulated shelterwood to remove the overstory and a thinning or cleaning in the young stand to reduce infection.

In irregular multistoried stands, older groups and patches should be clearcut and a new stand started. Dense young and immature groups and patches can be left untreated if mortality is not excessive and adjacent stands require no special protection. They may be thinned if stand density reduction is needed to improve scenic or other values.

In areas of high tree values, such as recreational, administrative, and homesites, infected branches can be pruned from lightly infected trees; but heavily infected trees must be cut (Hawksworth 1961, Hawksworth et al. 1968, Lightle and Hawksworth 1973).

If mountain pine beetle is present in the stand at an endemic level or in adjacent stands in sufficient numbers to make successful attacks, and less than the recommended basal area to be removed in the first cut is in susceptible trees, any attacked trees and all of the most susceptible trees should be removed in the first cut. This will include most of the larger diameter trees in single- and two-storied stands, and most of the mature groups and patches and scattered overstory trees in multistoried stands. Dense stands of understory trees and young and immature groups and patches should be thinned. Provision should be made to salvage attacked trees. Moreover, the second cut should be made within 10 years.

If more than the recommended basal area to be removed in the first cut is in susceptible and/or attacked trees, the manager has three options: (1) remove all the trees in single- and two-storied stands and all mature groups and patches in multistoried stands, followed by thinning in dense young and stands, patches, or groups; (2) remove the recommended basal area in attacked and susceptible trees, thin the dense stands, patches, and groups of young immature trees (6 to 8 inches d.b.h.) to GSL 60 to 80, and accept the risk of future losses; or (3) leave the stand uncut. However, any benefits of thinning are not likely to be realized if the thinned area is small and surrounded by unthinned stands sustaining an attack (Stevens et al. 1975). If the stand is partially cut or left uncut, some trees in the smaller diameter classes will survive.

If a single-, two-, or multistoried stand is sustaining an infestation that is at epidemic levels or building up and the manager chooses to either partially cut or leave the stand uncut, there is a risk of an outbreak that could destroy most of the infested merchantable stand and spread to adjacent stands.

Cutting to save the residual stand.—In shelterwood cutting, protection of the residual stand from logging damage is a primary concern. The residual stand includes merchantable trees left after standard shelterwood and reproduction established after the seed cut in standard shelterwood, and reproduction established after each cut in group shelterwood. Before the final harvest is made with standard shelterwood and before each entry with group shelterwood, the manager must determine if there is an acceptable stand of reproduction. Furthermore, the stand must be reevaluated after final harvest in standard shelterwood and after each entry with group shelterwood to determine the need for supplemental stocking. The same criteria used to evaluate advanced reproduction with a simulated shelterwood applies here.

Protection begins with a well-designed logging plan at the same time of the first cut. To minimize damage, the same protection measures for management with advanced reproduction apply here.

Slash disposal and seedbed preparation.—Some treatment of logging slash and unmerchantable material may be needed after each cut, especially if *Ips* populations are observed. Treatment should be confined to concentrations and that needed to reduce visual and insect impacts. Piling and burning slash may cause damage to the residual stand, and is expensive and time consuming. Spot burning usually is more effective if stands are open and slash accumulations are kept away from residual trees. Treatment in stands often can be limited to lopping and scattering, chipping along the roadway, and hand piling and burning to minimize damage, especially where utilization of small material for small posts and firewood removes much of the slash (fig. 15). In group shelterwood cutting, if there is not a manageable stand of advanced reproduction, dozers equipped with brush blades can be used to concentrate slash for burning in the openings. Piles should be kept small to reduce the amount of heat generated.

Figure 15.—Utilization of all usable material, including firewood, usually minimizes the need for slash disposal.

Figure 16.—Rubber tired skidders are too large to work well in seedbed preparation or slash disposal in partially cut stands.

On areas to be regenerated by new reproduction, a partial overstory canopy or trees standing around the margins of small openings provide two of the basic elements necessary for regeneration success—a seed source within effective seeding distance and an environment compatible with germination, initial survival, and seedling establishment. The manager must make sure that the third element—a suitable seedbed—is provided after the regeneration cut where standard shelterwood cutting is used and after each cut where group shelterwood or cuttings to convert irregular stand structures to managed stands is used.[2] Until special equipment is developed, seedbed preparation, as well as slash disposal, will pose problems. The equipment available is too large to work well around standing trees (fig. 16). Small dozers, other machines equipped with brush blades, or small crawler tractors pulling a toothed disk equipped with a hydraulic lift will have to be used; but they must be closely supervised to minimize damage to the residual stand.

UNEVEN-AGED CUTTING METHODS

Single- and two-storied ponderosa pine stands are best maintained under even-aged cutting methods, preferably some form of shelterwood. However, multistoried stands frequently are uneven- to broad-aged by even-aged groups and patches, or have diameter distributions more closely associated with uneven-aged stands. Moreover, uneven-aged management may be more compatible or desirable for some management objectives or resource needs. For example, the impact on the forest should be as light as possible in areas of steep topography and erosive soils or where management goals include maintenance of continuous forest canopy. Uneven-aged management may be more appropriate for these conditions and objectives.

Uneven-aged management includes cultural treatments, thinnings, and harvesting necessary to maintain

[2]*Discussion of the silvical requirements and cultural practices necessary for successful ponderosa pine regeneration in the Front Range is beyond the scope of this paper. For this information, see Schubert (1974).*

continuous high forest cover, provide for regeneration of desirable species, either continuously or at each harvest, and provide for controlled growth and development of trees through the range of size classes needed for sustained yield of forest products. Managed uneven-aged stands are characterized by trees of many sizes intermingled singly or in groups. Cutting methods do not produce stands of the same age that are large enough to be recognized as a stand. Forests are subdivided into recognizable units that can be located on the ground on the basis of timber type, site, logging requirements, etc., rather than acreage in stand-age classes. Growing stock is regulated by setting: (1) a residual stocking goal, in terms of basal area or volume, that must be maintained to provide adequate growth and yield, (2) a diameter distribution goal that will provide for regeneration, growth, and development of replacement trees, and (3) a maximum tree size goal. In addition, a decision must be made on how to handle small trees. Both individual-tree selection and group selection cutting methods will be considered in stands with irregular to all-aged structure (Alexander and Edminster 1977a, 1977b).

Individual-Tree Selection Cutting

This regeneration cutting method harvests trees in several or all diameter classes on an individual basis. Stands regenerate continuously. The ultimate objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (USDA Forest Service 1983). Choice of trees to be cut depends on their characteristics and relationship to stand structure goals set up to regulate the cut. This cutting method provides maximum flexibility in choosing trees to cut or leave and is appropriate only in uniformly spaced stands with irregular to all-aged structure. However, because of ponderosa pine's silvical characteristics, individual-tree selection cutting is not recommended in pure stands. In mixed ponderosa pine—Douglas-fir stands, individual-tree selection can be used; but few pines are likely to be established after initial cutting.

Group Selection Cutting

This regeneration cutting method harvests trees in groups, ranging from a fraction of an acre up to about 2 acres (USDA Forest Service 1983). It is similar to a group shelterwood except in the way the growing stock is regulated. The area cut is smaller than the minimum feasible for a single stand under even-aged management. Trees are marked on an individual-tree basis; but emphasis is on group characteristics, which means trees with high potential for future growth are removed along with trees with low growth potential. Loss in flexibility is partly offset by the opportunity to uniformly release established regeneration and reduce future logging damage. When groups are composed of only a few trees, the method can be used together with individual-tree selection cutting in mixed stands. This cutting method is most appropriate in irregular to broad-aged mixed or pure multistoried ponderosa pine stands that are clumpy, groupy, or patchy. However, it can be used in uniformly spaced stands with the size, shape, and arrangement of openings based on factors other than the natural stand conditions (Alexander and Edminster 1977a, 1977b).

Stand Structure Goals

Control of Stocking

The first step in applying a selection cut to a ponderosa pine stand is to determine the residual stocking level to be retained. Because total stand growth for many species under uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specific size, and requires a minimum investment in growing stock (Alexander and Edminster 1977b).

The residual stocking level with the best growth potential and most desirable appearance in pure or mixed ponderosa pine stands varies with species composition, management objectives, productivity, diameter distribution, etc. In unregulated old-growth ponderosa pine stands with irregular structure, stocking usually varies from 40 to 110 square feet of basal area per acre in trees in the 4-inch and larger diameter classes. Basal areas above 90 to 100 square feet per acre probably represent overstocking. While no guidelines are available for uneven-aged stands, residual stocking levels of GSL 40 to GSL 80 are suggested for managed even-aged stands, with the low site quality normally associated with ponderosa pine in the Front Range (Alexander and Edminster 1980). These levels should be useful in estimating initial residual stocking goals in terms of square feet of basal area per acre for that part of the stand that eventually will be regulated under uneven-aged management (Alexander and Edminster 1977b).

While these general recommendations are probably adequate to start with, use of yield tables for even-aged stands in setting stocking goals for uneven-aged stands assumes there is little difference between the growing stock of the two other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The result is likely to be a series of small, even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may develop with either individual-tree or group selection methods. Growing space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees of a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961).

Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size

The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth ponderosa pine stands with irregular spacing, in the Front Range, maximum diameter usually varies from 16 to 26 inches d.b.h., depending on stand density, site quality, species composition, etc. Examination of plot inventory information from unmanaged stands with irregular stand structure suggests that a diameter of 16 inches can be attained within the time period generally considered reasonable under the narrow range of site quality (SI 40–60) found in the Front Range and stocking levels likely to be management goals (GSL 40–80). In the absence of any information on growth rates in uneven-aged stands or rates of return for specific diameter stocking classes, a 16-inch maximum diameter seems a reasonable first approximation to set for timber production on lands of average site quality. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use reasons (Alexander and Edminster 1977b).

Control of Diameter Distribution

Control over distribution of tree diameters also is necessary to regulate yields under uneven-aged management. This most important step is accomplished by establishing the desired number of trees or basal area for each diameter class.

When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating diameter distributions in uneven-aged stands (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-inch diameter classes) have been recommended for various situations. The lower the q, the smaller is the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock in larger trees, for any residual stocking level, but may require periodic removal of the largest number of small trees in the diameter class when unregulated growing stock crosses the threshold into the proportion of the stand to be regulated (Alexander and Edminster 1977b).

Consider, for example, differences in the number of small and large trees maintained at a q level of 1.1, 1.3, and 1.5 in stands with the same residual basal area (60 square feet) (table 3). At all stocking levels considered appropriate for future management goals, many small trees would have to be cut under lower q levels at the threshold diameter class (in this example the 4-inch class). Fewer larger trees would be retained under higher q levels.

In the absence of any experience, data, or good growth and yield information, the best estimate of numbers of trees to leave by diameter classes is to use the lowest q value that is reasonable in terms of existing markets, stand conditions, and funds available for cultural work. Examination of plot data from a wide range of irregularly stocked old-growth ponderosa pine stands indicates that pretreatment distributions are likely to range between 1.2 and 1.5 for 2-inch classes. As a general recommendation, q levels between 1.2 and 1.4 appear to be reasonable initial goals for the first entry into unmanaged stands.

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tree diameter, and q levels have been selected, the specific structure for a stand can be calculated, provided that data are available to construct a stand table (Alexander and Edminster 1977b).

An existing old-growth ponderosa pine stand on the Manitou Experimental Forest in Colorado was selected to illustrate the procedure. The actual inventory data for the stand is shown in columns 1, 2, and 3 of table 4. A residual basal area of 60 square feet per acre in trees 4 inches d.b.h. and larger has been chosen. A maximum tree diameter of 16 inches d.b.h. was chosen, because it also appears to be a realistic goal to be attained in a

Table 3.—Residual stand structures for 60 square feet of basal area (BA) and maximum tree diameter of 16 inches d.b.h. for various q values.

	q = 1.1		q = 1.3		q = 1.5	
class	No. of trees	BA (ft.^{2})	No. of trees	BA (ft.^{2})	No. of trees	BA (ft.^{2})
4	20.28	1.77	38.83	3.39	63.00	5.50
6	18.59	3.65	29.85	5.86	41.93	8.23
8	16.72	5.84	22.97	8.02	28.01	9.78
10	15.29	8.34	17.64	9.62	18.66	10.18
12	13.81	10.85	13.58	10.67	12.45	9.78
14	12.59	13.46	10.45	11.17	8.29	8.86
16	11.50	16.06	8.04	11.23	5.52	7.71
Total	108.78	59.97	141.76	59.96	177.85	60.04

reasonable period of time. Finally, a q of 1.4 was chosen, because it approximates the q in the natural stand and does not require removal of many small trees. A lower q may be feasible; but it would require heavy cutting in lower diameter classes.

To determine the residual stand goal, the value of the residual density parameter k corresponding to a basal area of 60 square feet must be calculated. Values needed for this computation with a q of 1.4 are given in column 5 of table 5. The value of k is computed as

$$k = \frac{60.0}{0.62428 - 0.01558} = 98.57072$$

where 60.0 is the desired basal area per acre, 0.62428 is the table value for the desired maximum tree diameter class of 16 inches, and 0.01558 is the table value for the 2-inch class. Note that the value for the 2-inch class is subtracted from the 16-inch class value, because trees smaller than the 4-inch class are not considered in the management guidelines. Desired residual number of trees in each diameter class (column 4 of table 4) can be directly calculated by multiplying the proper diameter class values given in column 5 of table 6 by the value of k. The desired residual basal area in each diameter class (column 5 of table 4) can be calculated by multiplying the residual number of trees in each diameter class by the tree basal area.

Comparing actual and desired diameter distributions shows where deficits and surpluses occur (fig. 17). To bring this stand under management, the number of trees should be allowed to increase in the diameter classes that are below the idealized stocking curve, with cutting limited to those diameter classes with surplus trees. As a guide, enough trees should be left above the curve in surplus diameter classes to balance the deficit in trees in diameter classes below the curve. In this example, there were no deficits. All surplus trees were cut in the 4- to 16-inch diameter classes. The final stand structure is shown in fig. 18 and columns 6 and 7 of table 4. Columns 8 and 9 show the trees and basal area removed.

Table 4.—Actual stand conditions and management goals for a ponderosa pine stand. All data are on a per acre basis—stand goals q = 1.4, residual basal area 60 square feet, maximum tree diameter of 16 inches d.b.h.

Diameter Class	Actual stand		Residual stand goal		Final stand		Cut	
	Trees	BA	Trees	BA	Trees	BA	Trees	BA
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
4	58	5.06	50.29	4.39	50	4.36	8	0.70
6	41	8.05	35.92	7.05	36	7.07	5	0.98
8	42	14.66	25.66	8.96	26	9.08	16	5.58
10	19	10.36	18.33	10.00	18	9.82	1	0.54
12	18	14.13	13.09	10.28	13	10.21	5	3.92
14	19	20.31	9.35	10.00	9	9.62	10	10.69
16	14	19.55	6.68	9.33	7	9.77	7	9.78
18	1	1.77	0	0	0	0	1	1.77
20	1	2.18	0	0	0	0	1	2.18
22	2	5.28	0	0	0	0	2	5.28
Total	215	101.35	159.32	60.01	159	59.93	56	41.42

Table 5.—Values needed to compute k for different q ratios and diameter ranges using basal area as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes	q ratio				
	1.1	1.2	1.3	1.4	1.5
(1)	(2)	(3)	(4)	(5)	(6)
2	0.01983	0.01818	0.01678	0.01558	0.01454
4	.09196	.07878	.06842	.06011	.05333
6	.23948	.19241	.15779	.13166	.11151
8	.47790	.36075	.28001	.22253	.18046
10	.81656	.57994	.42691	.32394	.25228
12	1.25990	.84297	.58963	.42825	.32124
14	1.80848	1.14132	.75999	.52966	.38380
16	2.45985	1.46605	.93116	.62428	.43828
18	3.20930	1.80854	1.09780	.70981	.48425
20	4.05043	2.16089	1.25606	.78523	.52209
22	4.97568	2.51618	1.40336	.85042	.55251
24	5.97669	2.86853	1.53820	.90583	.57682

Table 6.—Values needed to compute desired number of residual trees for different q ratios (Alexander and Edminster 1977b).

2-inch diameter classes D_i (1)	q ratio 1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)
2	0.909091	0.833333	0.769231	0.714286	0.666667
4	.826446	.694444	.591716	.510204	.444444
6	.751315	.578704	.455166	.364431	.296296
8	.683013	.482253	.350128	.260308	.197531
10	.620921	.401878	.269329	.185934	.131687
12	.564474	.334898	.207176	.132810	.087791
14	.513158	.279082	.159366	.094865	.058528
16	.466507	.232568	.122589	.067760	.039018
18	.424098	.193807	.094300	.048400	.026012
20	.385543	.161506	.072538	.034572	.017342
22	.350494	.134588	.055799	.024694	.011561
24	.318631	.112157	.042922	.017639	.007707

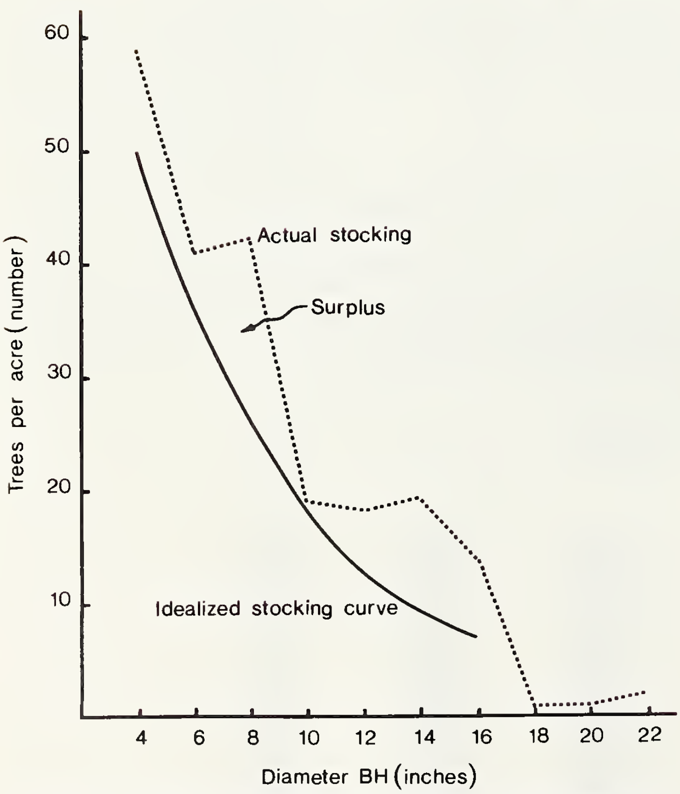

Figure 17.—Actual stocking curve from data collected on the Manitou Experimental Forest and the idealized stocking curve based on stand structure goals.

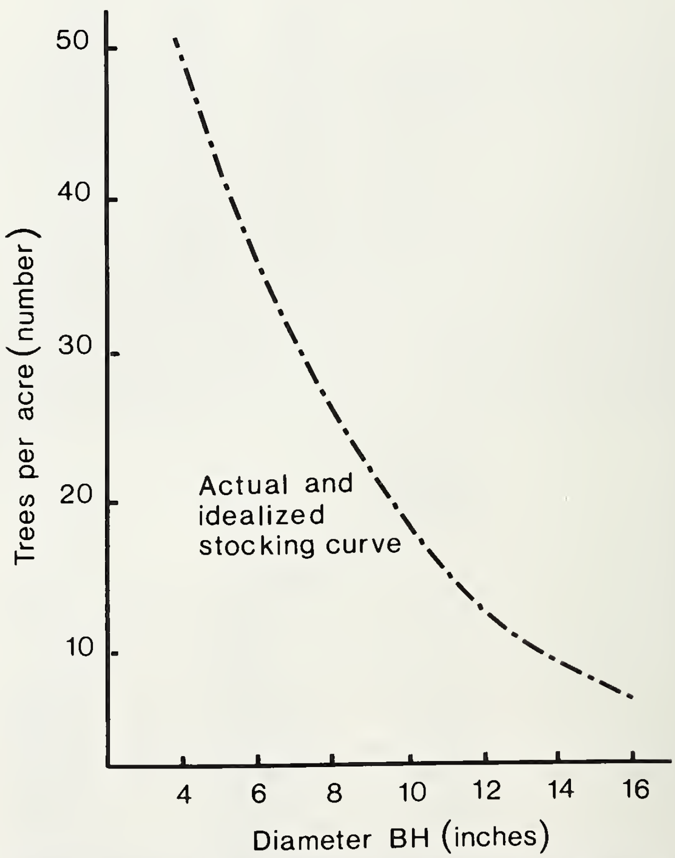

Figure 18.—Actual and recommended stocking curve based on stand structure goals are the same in this example.

How to Handle Small Trees

The threshold diameter class also must be determined. Calculations often are made down to the 4-inch diameter class by 2-inch classes, because often there are small trees below minimum merchantable diameter, especially in mixed stands. They compete with larger stems for growing space. More important, these trees provide ingrowth into merchantable size classes needed to practice selection silviculture.

Although small trees should not be ignored in inventory and record keeping, it may be neither desirable nor possible to regulate the number of them. In ponderosa pine forests in the central Rocky Mountains, minimum merchantable diameter is usually 5 to 8 inches. Regulation of the number of trees below this size requires an investment in silvicultural work that may not be recaptured under current market conditions. However, if trees below minimum merchantable size are left unregulated, cutting must always be heavy in the threshold diameter classes to bring ingrowth trees down to the desired number. It also means that more growing space is required for small trees than called for by the idealized stand structure. Moreover, the higher the threshold diameter class, the greater is the proportion of the stand that is unregulated. More growing space is occupied by trees of low value that will be cut as soon as they cross the threshold diameter (Alexander and Edminster 1977b).

Marking Trees

After residual stocking goals have been calculated and a decision has been made on how to handle small trees, the stand must be marked. Marking is difficult, because the marker must designate cut or leave trees, usually with one pass through the stand, based on limited inventory data. At the same time, the marker must apply good silviculture and be aware of economic limitations. As a general rule, good silvicultural prescriptions are more important than strict adherence to structural goals, especially in unregulated stands being cut for the first time. However, marking without a structural goal—or prescribing structural goals than cannot be attained or applied—defeats the objective of regulation.

Because marking for individual-tree selection cutting is more complex than for other systems, some formal control procedure is necessary. Often only an estimate of the initial desired residual diameter distribution is needed. With these estimates, basal areas and number of trees to be removed per acre by diameter classes can be determined. Control is maintained by a process of successive checks of residual versus the goal. For example, the markers should systematically make prism estimates of the residual stand after marking, recording trees by 2- or 4-inch classes on a standard cumulative tally sheet. Periodically, they should convert the prism tally to trees per acre, and compare their average prism estimate to the structural goal. Markers must then adjust to any serious deviation from the structural goal, such as too heavy marking in some diameter classes and too light in others. Their next check will determine if progress is being made or if further changes are needed. By this process, the average residual stand should come fairly close to the structural goal (Alexander and Edminster 1977b).

Marking under group selection cutting is less complex than under individual-tree selection; but control over the diameter distribution is also necessary. The objective is to create a series of openings over time and space with each opening containing a given diameter class.

It is not likely that unregulated stands will be brought under management with one entry or even a series of entries. It is more likely that limitations imposed by stand conditions, dwarf mistletoe, and mountain pine beetle susceptibility will result in either over- or undercutting, at least in the first entry.

Recommendations for Selection Cutting

These are based on experience, and dwarf mistletoe and mountain pine beetle susceptibility. Selection cutting methods are appropriate for multistoried pure or mixed stands with irregular or uneven-age stand structure. Individual-tree selection should be confined to mixed stands with uniform spacing. Group selection can be used in stands with either clumpy, groupy, or patchy spacing, or uniform spacing. Selection cutting methods are not appropriate in stands sustaining a mountain pine beetle attack or in stands where enough beetles are present within the stand or adjacent stands to make successful attacks, or in stands where the dwarf mistletoe rating is 3 or more.

Stand Structure Goals, Cutting Treatments, and Reentry Schedules

The stocking goal for the initial entry should be set so that not more than 30% to 40% of the stand basal area is removed. With individual-tree selection, the cut should be distributed over the entire area. With group selection, not more than one-third of the area should be cut. If the stand is groupy, clumpy, or patchy, the size of opening should be determined by the size of the group, clump, or patch. If the stand is uniformly spaced, the size of the opening should not exceed 2 to 3 times tree height. Keep the openings small.

Maximum tree diameter should not exceed that attained in the unmanaged stand. The diameter distribution should be set at a "q" value that most closely approximates the natural "q" value of the stand. However, remember that low q values require cutting a larger number of trees at the threshold diameter class and high q values retain few larger trees. The threshold value should be set at the smallest diameter class practical. All trees below the threshold diameter class are unregulated. Some diameter classes will have a surplus of trees and some will have a deficit. Surpluses and deficits must be balanced if the residual basal area is to maintained. Subsequent entries should be made at 10- to 30-year intervals. While it would be desirable to enter the stand at 10-year intervals, it is not likely that growth rates will permit this in most instances. Some diameter classes will not be completely represented; therefore, volumes available for cutting may not warrant a 10-year reentry until a controlled diameter distribution is attained.

Protecting the Residual Stand

Protection of the residual stand is critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees in the openings or marking a small clump of trees where felling one large tree will damage several adjacent trees. Procedures outlined for protecting the residual and disposing of slash for shelterwood cutting should be followed here.

COST OF SALE ADMINISTRATION AND LOGGING

One of the most important factors affecting the administrative cost of selling timber is the number of entries needed for harvesting. Simulated shelterwood requires only one entry. Standard shelterwood requires two to three entries. Group shelterwood and individual-tree and group selection require from three to six entries, depending upon cutting cycles. In managed stands, even-aged systems require a minimum of two additional entries for thinnings; but the number of entries under uneven-aged systems would not change.

Costs of sale layout, marking, and sale contract administration are lower for simulated and group shelterwood, group selection (when groups are near the maximum size), and the final cut of standard shelterwood than for individual-tree selection, and the intermediate, preparatory, and seed cuts of standard shelterwood. Costs are reduced, because only cutting boundaries are marked, and no time is spent deciding which trees to cut or leave. Sale administration is easier, because there are no residual trees to protect and no opportunity to cut unmarked trees. However, reproduction must be protected at the time of final cut under any shelterwood system.

Timber harvesting in the Front Range may require road construction. Shelterwood is the most economical method in terms of volume removed per unit of road; individual-tree selection is the most expensive. Development of a transportation system to manage forests is a costly front-end investment that will require funding in addition to the value of stumpage at the time of first entry. Once the transportation system has been constructed, road costs should be independent of cutting method.

The maximum volume per acre is usually produced in the final cut of standard shelterwood or simulated shelterwood; but each cutting method requires maximum concern for protection of the residual stand. The first entry of a standard shelterwood is intermediate in volume production per acre, requires moderate concern for the residual stand, and places some constraints on selection of equipment. Individual-tree selection requires maximum concern for the residual stand. Group selection and group shelterwood require slightly less if the size of the opening is near maximum. Under uneven-aged and group shelterwood cutting methods, volumes per entry are intermediate, size-class diversity of products harvested is minimum, and a choice of logging equipment is limited.

MULTIPLE-USE SILVICULTURE

POTENTIAL TIMBER YIELDS

Highest potential timber yields can be realized under a two-cut shelterwood option, provided that the final harvest with a shelterwood is made within 5 years after regeneration is established. Comparable growth rates can be achieved with group shelterwood and group selection only if the openings are near the maximum size (2 acres). Total yields will be less under a three-cut shelterwood. Under simulated shelterwood, yield increases resulting from reduction in rotation length may be offset by the slower growth of trees in the replacement stand. Yields will be less under individual-tree and group selection in situations where very small openings are cut.

SOIL WATER RESOURCES

Water Yield

In ponderosa pine forests in the Front Range, the proportion of water yielded to precipitation is low, because about two-thirds of the precipitation falls as rain during the growing season, when evapotranspiration losses are high, and winter snowpack is intermittent. Consequently, of the 15 to 20 inches of precipitation, only about 10% to 25% (2–5 inches) becomes streamflow (Gary 1975). Although water yields are small compared to higher elevation forests, they are important. The largest increases in water yield would occur if trees were harvested in small clearcut patches about 5 tree heights in diameter interspersed so that they are about 5 to 8 tree heights apart. The increase in runoff is largely a result of reduced interception and evapotranspiration; but it also may be affected by redistribution of precipitation. However, clearcutting is not a recommended option in ponderosa pine in the Front Range because of other resource requirements, except in stands with serious insect and disease problems.

Group shelterwood and group selection cutting recommended for patchy and groupy uneven-aged stands can be nearly as favorable for increasing streamflow as patch clearcutting, if openings are near the maximum size of 2 acres. In the low precipitation-high energy environment of the Front Range, partial cutting treatments such as individual-tree selection and shelterwood are not likely to change water yields from that available from uncut forests.

Soil Erosion

Soil and site conditions are not the same in all ponderosa pine forests; but many of them grow on either residual soils derived from granitic schists or alluvium soils derived from granitic rock. These soils are generally considered to be naturally erosive. When protective plant cover is removed and soils distributed by roadbuilding, logging, and fire, natural erosion processes are accelerated (Gary 1975). Careful location, construction, and maintenance of skid and haul roads associated with any cutting method should not cause a lasting increase in erosion. For example, Dortignac and Love (1966) concluded that when organic materials on the ground exceeded 2 tons per acre, and less than 30% of the treated area was disturbed, erosion losses will usually be less than 500 pounds per inch of runoff.

Nutrient Loss and Stream Water Temperature Changes

Removal of logs in timber harvest represents a small and temporary net loss of nutrients, because only a minor proportion of the nutrients taken up by a tree is stored in the bole. Cutting that removes all, or most all trees, results in a greater immediate loss than partial cutting; but over a rotation, the losses would balance out because of more frequent cuts under the partial cutting methods. Furthermore, nutrients lost after cutting all, or most all trees, should be replaced in 10 to 20 years through natural cycling as regeneration becomes established.

Increases in stream temperature can be avoided, even with clearcutting, by retaining a border of trees along stream channels. Actually, clearcutting to the stream channel and subsequent warming of the water may be advantageous where streams are frequently small and too cold to support adequate food supplies for fish.

WILDLIFE AND RANGE RESOURCES

Game Habitat

Old-growth ponderosa pine stands provide habitat for a variety of game animals. Group shelterwood and group selection provide the largest increases in quantity and quality of forage for big game; but use often is limited by the amount of cover available for hiding, resting, and ruminating.

Dispersed openings 2 and 5 acres in size are used more by deer and elk than smaller or larger openings or uncut timber. Very small openings provide little diversity; game animals usually use only the edges around large openings. As trees grow to seedling and sapling size, forage production in cleared areas diminishes (Currie 1975), but cover increases until it reaches maximum in mature stands.

Standard shelterwood cutting provides less forage for big game than cutting methods that create openings; the reduction is in proportion to the density of the overstory and length of time it is retained. Shelterwood cutting also provides less cover than an uncut forest. Individual-tree selection provides forage and cover comparable to uncut forests, thereby maintaining one type of habitat at the expense of creating diversity.

Nongame Habitat

Information is limited on the relationship of cutting methods in ponderosa pine forests in Front Range to specific nongame habitat requirements; but it is possible to estimate probable effects. Group shelterwood and group selection that create small, dispersed openings provide a wide range of habitats attractive to some birds and small mammals by increasing the amount of nontree vegetation—at least initially—and length of edge between dissimilar vegetation types.

Standard shelterwood cutting provides a variety of habitats attractive to species that forage in stands with widely spaced trees but not to those that require closed forests or fully open plant communities. Under this method, trees are still available for nesting, denning, and feeding until the final harvest, when consideration should be given to retaining some of the limby live trees and snags and live trees with cavities. For example, large ponderosa pines are preferred for food and cover by Abert's squirrels (Keith 1965). Conditions are improved when the rather uniform spacings that usually result from partial cuttings are interrupted by occasional clumps of three or four closely spaced large trees. Maintenance of squirrel populations, therefore, requires avoiding conversion of large areas to seedling and sapling stands. Development of scattered, young stands of reasonable area creates no special problems.

Harvesting old-growth timber can be devasting to species like the flammulated owl that nest or den in snags and in cavities of live trees, feed largely on insects, and require solitary habitats normally associated with large areas of old-growth. Most nongame species have a minimum habitat size below which they can not exist. Small patches of varying ages and structure and all-aged stands may reduce the number of species. Individual-tree selection provides the least horizontal diversity and favors species attracted to uncut forests or that require vertical diversity. However, snags and live tree cavities can be retained under any silvicultural system.

The low-vigor, large-limbed, or dead trees used by wildlife would be prime choices for removal if special effort is not made to save them. So few trees per acre are involved in this type of habitat maintenance that their preservation has a negligible adverse effect on the appearance of the forest and other values. Regardless of the silvicultural methods applied, these trees should remain untouched as long as they are useful to wildlife.

Lifestock Grazing

Historically, ponderosa pine and associated bunchgrass ranges have been important livestock producing areas in the Front Range. The pine and bunchgrass type is a complex of plant communities. Its one apparent and common characteristic is open grassland parks interspersed with forested areas. Natural forested areas may be open with extensive herbaceous understory vegetation or closed with little or no understory vegetation (Currie 1975). Forage production and changes in species composition and palatability vary considerably, depending upon plant community and successional stage. Forage production increases most when group shelterwood and group selection openings are cut in dense stands. The increase in forage production in these openings persists for 10 to 20 years before competition from tree reproduction begins to reduce understory vigor and composition. It can be maintained only by frequent intermediate cuttings to keep density low. Forage production after shelterwood and individual-tree selection cutting is in relation to the amount of overstory retained and time between entries in the stand.

RECREATION AND ESTHETICS

Ponderosa pine forests in the Front Range provide a variety of recreation opportunities. Users who hike, backpack, or view scenery are generally attracted to forests whose natural appearance is little altered by human activities (Calvin 1972). In contrast, hunters have best success where human activities are apparent—timber sales and other areas readily accessible by roads. Fishing is mostly done in accessible lakes, reservoirs, and streams. Generally, most camping opportunities are at both publicly and privately developed sites served by roads. Most scenery viewing is by automobile on developed roads. Finally, some forms of recreation, such as mountain home development, require drastic modification of the natural forest landscape.

Cutting openings has the greatest visual impact, and individual-tree selection has the least. However, variety typical of forests whose texture is broken by natural openings is preferred to the monotony of unbroken forest landscapes (Kaplan 1973).

To enhance amenity values, cutting openings to harvest timber and improve wildlife habitat should be a repetition of natural shapes visually tied together to create a balanced and unified pattern that will complement the landscape (Barnes 1971). This is especially important for openings in the middleground and background seen from a distance. Standard or simulated shelterwood or individual-tree selection can be used to retain a landscape in foregrounds.

Individual-tree selection, group selection, and group shelterwood cutting are appropriate in high-use recreation areas, travel influence zones, scenic-view areas, and subdivision developments where permanent forest cover is desired. The visual impact of logging can be minimized by cleanup of debris and slash and by careful location of roads.

COMPARISON OF CUTTING METHODS

No silvicultural system or cutting method (including no cutting at all) meets all resource needs. Group shelterwood and group selection that cut small openings provides maximum yields of timber at less costs, promotes the largest increases in water production without serious reduction in quality, produces diversity of food supply and cover favored by many wildlife species, and is necessary for the development of recreation sites and home subdivisions. Production and utilization of livestock forage may be less than in larger openings, however. Cutting openings can create adverse visual effects if no thought is given to the size and arrangement of the openings; but it can also be used to create landscape variety that will enhance amenity values.

Standard and simulated shelterwood cutting also provide maximum timber yields over the same time interval, but at increased costs; they produce a wide range of wildlife habitats, but with less forage than openings and less cover than uncut forests. Water yields are not increased over natural streamflow, however. Shelterwood cutting provides a partial retention of the forest landscape, particularly when the overstory is retained for a long time.

Individual-tree selection cutting is not appropriate for timber production in pure ponderosa pine stands, but could be used to meet other resource needs. Water yields are not greater than from uncut forests. Individual-tree selection cutting provides minimum horizontal diversity in wildlife habitat, but favors species attracted to uncut forests. It also provides maximum partial retention of the natural forest landscape. Group selection with very small openings accomplishes about the same things as individual-tree selection.

Not all resource needs can be met on a given site nor is any one cutting method compatible with all uses. Land managers must recognize the potential multiple-use values of each area, determine the primary and secondary uses, and then select the management alternative that is most likely to enhance or protect these values within the limits imposed by stand conditions and damaging agents. On an individual site, some uses probably must be sacrificed or diminished to maintain the quantity and quality of others.

LITERATURE CITED

Alexander, Robert R., and Carleton B. Edminster. 1977a. Regulation and control of cut under uneven-aged management. USDA Forest Service Research Paper RM–182, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1977b. Uneven-aged management of old-growth spruce-fir forests: cutting methods and stand structure goals for initial entry. USDA Forest Service Research Paper RM–186, 12 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1980. Management of ponderosa pine in even-aged stands in the Southwest. USDA Forest Service Research Paper RM–225, 11 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Baker, Frederick S. 1949. A revised tolerance table. Journal of Forestry 47:179–181.

Barnes, R. Lawrence. 1971. Patterned tree harvest proposed. Western Conservation Journal 28:44–47.

Barrett, James W., Philip M. McDonald, Frank Ronco, Jr., and Russell A. Ryder. 1980. Interior ponderosa pine 237. p. 114–115. *In* F. A. Eyre, editor. Forest cover types of the United States and Canada. Society of American Foresters, Washington, D.C.

Beatty, Jerome S. 1982. Southwestern dwarf mistletoe (*Arceuthobium vaginatum* subsp. *Cryptopodium* (Engelm.)) gill, in ponderosa pine. USDA Forest Service Integrated Pest Management Guide R–3 82–13, 12 p. Forest Pest Management State and Private Forestry, Southwestern Region, Albuquerque, N. Mex.

Bond, E. W. 1952. Growing stock differences in even-aged and all-aged forests. Journal of Forestry 50:691–693.

Bourne, R. 1951. A fallacy in the theory of growing stock. Forestry 24:6–18.

Calvin, J. S. 1972. An attempt at assessing preferences for natural landscapes. Environment and Behavior 4(4):447–470.

Clapp, Earle. 1912. Silvicultural systems for western yellow pine. Society of American Foresters, Proceedings 7:168–176.

Currie, Pat O. 1975. Grazing management of ponderosa pine-bunchgrass ranges of the central Rocky Mountains: the status of our knowledge. USDA Forest Service Research Paper RM–159, 24 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Dortignac, E. J., and L. D. Love. 1960. Relation of plant cover to infiltration and erosion in ponderosa pine forests of Colorado. American Society of Agricultural Engineers Transactions 3:58–61.

Furniss, R. L., and V. M. Carolin. 1977. Western forest insects. U.S. Department of Agriculture, Miscellaneous Publication 1339, 654 p. Washington, D.C.

Gary, Howard L. 1975. Watershed management problems and opportunities for the Colorado Front Range ponderosa pine zone: the status of our knowledge. USDA Forest Service Research Paper RM–139, 32 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Gary, Howard L. 1985. A summary of research at the Manitou Experimental Forest, Colorado. USDA Forest Service General Technical Report RM–116, 24 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Green, Allen W., and Duane D. Van Hooser. 1983. Forest resources of the Rocky Mountain states. USDA Forest Service Research Bulletin INT–33, 127 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Hawksworth, Frank G. 1961. Dwarf mistletoe of ponderosa pine in the Southwest. U.S. Department of Agriculture Technical Bulletin 1246, 112 p. Washington, D.C.

Hawksworth, Frank G. 1977. The 6-class dwarf mistletoe rating system. USDA Forest Service General Technical Report RM–48, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hawksworth, Frank G, James L. Stewart, and Wilmer F. Bailey. 1968. You can save your pines from dwarf mistletoe. USDA Forest Service Research Paper RM–35, 20 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Heidmann, L. J. 1983. Silvicultural control of dwarf mistletoe in southwestern ponderosa pine. USDA Forest Service Research Note RM–433, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hepting, George H. 1971. Diseases of forest and shade trees of the United States. U.S. Department of Agriculture Handbook 386, 685 p. Washington, D.C.

Johnson, David W., Frank G. Hawksworth, and Laura M. Merrill. 1984. Ponderosa pine dwarf mistletoe loss assessment survey on national forest land in Colorado. USDA Forest Service Technical Report R–2–27, 13 p. Timber, Forest Pest, and Cooperative Forestry Management, Rocky Mountain Region, Denver, Colo.

Kaplan, R. 1973. Predictors of environmental preferences. Designers and "clients". p. 265–274. *In* W. F. E. Prieser, editor. Environmental Design Research. Proceedings of 4th International EDRA Conference. [Blacksburg, Va., April, 1973]. Dowden, Hutchinson, and Ross, Stroudsburg, Penn.

Keith, James O. 1965. The Abert squirrel and its dependence on ponderosa pine. Ecology 46:150–163.

Lightle, Paul C., and Frank G. Hawksworth. 1973. Control of dwarf mistletoe in heavily used ponderosa pine recreation forests: Grand Canyon, Arizona. USDA Forest Service Research Paper RM–106, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Lightle, Paul C., and Melvyn J. Weiss. 1974. Dwarf mistletoe of ponderosa pine in the Southwest. U.S. Department of Agriculture Forest Pest Leaflet 19, 8 p. Washington, D.C.

McCambridge, William F., and Galen C. Trostle. 1972. The mountain pine beetle. U.S. Department of Agriculture Forest Pest Leaflet 2, 6 p. Washington, D.C.

Meyer, H. A. 1952. Structure, growth, and drain in balanced uneven-aged forests. Journal of Forestry 50:85–92.

Meyer, H. A., A. D. Rechnagel, D. D. Stevenson, and R. A. Bartoo. 1961. Forest Management. 282 p. The Roland Press Company, New York, N.Y.

Myers, Clifford A. 1974. Multipurpose silviculture in ponderosa pine stands of the montane zone of central Colorado. USDA Forest Service Research Paper RM–132, 15 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Pearson, G. A. 1910. Reproduction of western yellow pine in the Southwest. U.S. Forest Service Circular 174, 16 p. Washington, D.C.

Peterson, R. S., and R. G. Shurtleff, Jr. 1965. Mycelium of limb rust fungi. American Journal of Botany 25: 519–525.

Reynolds, R. R. 1954. Growing stock in all-aged forests. Journal of Forestry 52:744–747.

Ronco, Frank, Jr., and Kenneth L. Ready. 1983. Southwestern ponderosa pine. p. 70–72. *In* Silvicultural systems for major forest types of the United States. R. E. Burns, technical compiler. U.S. Department of Agriculture, Forest Service, Handbook 445, 191 p. Washington, D.C.

Sartwell, Charles, R. F. Schmitz, W. J. Buckhorn. 1971. Pine engraver, *Ips pini*, in the western States. U.S. Department of Agriculture, Forest Service, Forest Pest Leaflet 122, 5 p. Washington, D.C.

Schubert, Gilbert H. 1974. Silviculture of southwestern ponderosa pine: the status of our knowledge. USDA Forest Service Research Paper RM–123, 71 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Stevens, Robert E., J. Wayne Brewer, and David A. Leatherman. 1980. Insects associated with ponderosa pine in Colorado. USDA Forest Service General Technical Report RM–75, 42 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Stevens, Robert E., Clifford A. Myers, William F. McCambridge, George L. Downing, and John G. Laut. 1975. Mountain pine beetle in Front Range ponderosa pine: what it's doing and how to control it. USDA Forest Service General Technical Report RM–7, 3 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

U.S. Department of Agriculture, Forest Service. 1983. Silvicultural systems for the major forest types of the United States. R. E. Burns, technical compiler. Agricultural Handbook No. 445, 191 p. Washington, D.C.

Alexander, Robert R. 1986. Silvicultural systems and cutting methods for ponderosa pine forests in the Front Range of the central Rocky Mountains. USDA Forest Service General Technical Report RM–128, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed ponderosa pine forests in the Front Range into managed stands for a variety of resource needs. Guidelines consider stand conditions, and insect and disease susceptibility. Cutting practices are designed to integrate maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing, with providing wood products.

Keywords: Silvicultural systems, timber harvesting, *Pinus ponderosa*

Alexander, Robert R. 1986. Silvicultural systems and cutting methods for ponderosa pine forests in the Front Range of the central Rocky Mountains. USDA Forest Service General Technical Report RM–128, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed ponderosa pine forests in the Front Range into managed stands for a variety of resource needs. Guidelines consider stand conditions, and insect and disease susceptibility. Cutting practices are designed to integrate maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing, with providing wood products.

Keywords: Silvicultural systems, timber harvesting, *Pinus ponderosa*

Alexander, Robert R. 1986. Silvicultural systems and cutting methods for ponderosa pine forests in the Front Range of the central Rocky Mountains. USDA Forest Service General Technical Report RM–128, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed ponderosa pine forests in the Front Range into managed stands for a variety of resource needs. Guidelines consider stand conditions, and insect and disease susceptibility. Cutting practices are designed to integrate maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing, with providing wood products.

Keywords: Silvicultural systems, timber harvesting, *Pinus ponderosa*

Alexander, Robert R. 1986. Silvicultural systems and cutting methods for ponderosa pine forests in the Front Range of the central Rocky Mountains. USDA Forest Service General Technical Report RM–128, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed ponderosa pine forests in the Front Range into managed stands for a variety of resource needs. Guidelines consider stand conditions, and insect and disease susceptibility. Cutting practices are designed to integrate maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing, with providing wood products.

Keywords: Silvicultural systems, timber harvesting, *Pinus ponderosa*

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526